FISHERIES AGENCIES AND MARINE BIODIVERSITY[1]

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Abstract

In addition to the potential negative impacts on biodiversity from fishing activities, there are positive aspects as well. Fisheries agencies are among the best equipped organizations to examine questions involving marine biodiversity because of their long history of studying marine populations. Furthermore, expansion of their involvement in these questions is in the agencies' interest. Fisheries management depends not only on the accurate identification of target species, but also on understanding the ecosystems from which they come. Systematics is the base from which many questions about biodiversity must be addressed. Taxonomy is a critical tool for ecologists. Therefore, in addition to training new systematists, the systematics community must develop better ways to disseminate the information it develops and train other biologists to be proficient in taxonomy. Closer cooperation between fisheries and systematics is urgently needed to develop the knowledge and skills necessary for assessment and maintenance of marine biological diversity.

The problem of conserving biological diversity has received so much attention that almost any scientifically literate person will have heard of it by now. It is rapidly becoming an international conservation priority emphasized in both the scientific (e.g., Harper & Hawksworth, 1994; Eldridge, 1992) and popular (e.g., Sawhill, 1994) press. Governments at all levels in nations around the world are debating and implementing legislative and executive actions to assess and preserve biodiversity. The Convention on Biological Diversity adopted as part of the 1992 United Nations Conference on Environment and Development calls for countries to undertake two major tasks: (1) identify the components of biological diversity that are important for conservation and sustainable use, and (2) integrate biodiversity concerns into socio-economic planning. Institutions that bring together the people who manage, use, and study biodiversity are crucial for achieving long-term responsible management of biological resources.

The widespread debate about what biodiversity is has resulted in a consensus that three levels of diversity are included: genetic diversity within species, phylogenetic diversity (species diversity including consideration of higher-level relationships), and diversity of ecosystems. Debate continues over the relative importance of these components (Barbault & Hochberg, 1992; Brooks et al., 1992; Franklin, 1993; Stiassny, 1992), but degradation at one level affects the other levels as well. For instance, reducing the phylogenetic diversity in model ecosystems alters ecosystem function (Naeen et al., 1994, 1995). This is very important in the context of marine fisheries.

Marine Biodiversity

Consideration of marine and estuarine ecosystems generally has lagged behind terrestrial and freshwater concerns for biodiversity (Norse, 1993; Ray & Grassle, 1991). Aside from early comparisons between tropical rainforests and coral reefs, which are spectacularly diverse and easily visited (Jackson, 1991), marine habitats have remained largely "out of sight and out of mind" at many of the colloquia on biodiversity. This is despite the fact that marine environments occupy 71% of the area and more than 95% of the volume of the biosphere (Angel, 1993). A recent focus on marine biodiversity (e.g., National Research Council, 1995; Vincent & Clarke, 1995) has begun to correct this oversight.

Points made in the many discussions on terrestrial biodiversity cannot simply be extrapolated to the marine environment. The nature of life in the sea is very different from that of terrestrial and freshwater environments (Peterson, 1992; Steele, 1985, 1991). This is especially true in the pelagic (Angel, 1992) and deep-sea (Grassle, 1991) realms. Many more differences in basic body plan, as represented by diversity of phyla, are found in the sea

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than anywhere else (Ray & Grassle, 1991). Life history traits of marine organisms differ greatly from those on land or in fresh waters, particularly with regard to dispersal (Strathmann, 1990). Coastal marine and estuarine ecosystems supply important services to people but suffer from anthropogenic alterations, ironically resulting from the human attraction to the coasts (Ray, 1991).

The difficulty of basic questions about the nature of biological diversity in the sea is increased by our comparative lack of knowledge about marine organisms. Estimates of the number of marine species vary by orders of magnitude (Briggs, 1994; Grassle & Maciolek, 1992; May, 1992, 1994). Population characteristics of marine species are not easily comparable with the better studied examples on land (Palumbi, 1992). Evidence is accumulating for surprisingly high genetic variability of marine populations in currently recognized species such as the common American oyster (Palumbi, 1994) and for the presence of many complexes of morphologically very similar sibling species (Knowlton, 1993), which contrasts with the terrestrial situation. It has been argued that Recent extinctions are not very common in the sea (Culotta, 1994), and conversely, that such extinctions may be commonly occurring but we lack the knowledge to recognize them (Carlton, 1993). Even if there are fewer, widespread species and comparatively few extinctions, it is likely that such a situation increases the importance of each extinction for the health of the ecosystem. Indeed, understanding phylogenetic diversity in marine animals with extensive fossil records, such as foraminifera and mollusks, may allow detailed investigations of the history of life and the processes of diversification (Buzas & Culver, 1991; Jablonski, 1993).

Fishing Effects

Marine fisheries are among the many human activities that impact diversity in marine ecosystems (Messieh et al., 1991). Fisheries, however, specifically target biological resources for harvest. The impact of assorted fisheries varies with the methods employed (Norse, 1993). Whereas some particularly destructive methods, such as dynamite fishing, have been widely prohibited, other methods are a continuing source of controversy. For instance, concerns about the effects of trawling have been voiced for centuries (de Groot, 1984). Of particular concern lately have been bycatch, the incidental mortality of non-target species, and physical disruption of the environment (Kennelly, 1995; Hendrickson & Griffin, 1993). Numerous studies continue to show that these effects vary among habitats (particularly bottom type) and target species (e.g., Hamre, 1994; Riemann & Hoffmann, 1991; Ryan & Moloney, 1988; Van Dolah et al., 1991).

Recently developed fishing methods, such as large drifting pelagic gill nets made of synthetic materials, are controversial (Norse, 1993). The Japanese driftnet fishery for squid began in 1978. By 1986, as many as 36 million "tans" (monofilament gillnet panels 30–50 m long and 7–10 m deep) were being set each year by Japanese vessels (Yatsu et al., 1994a). The Japanese National Research Institute of Far Seas Fisheries estimated that between 1989 and 1991 the bycatch of this fishery included 57,675 cetaceans. Other bycatch of this fishery included millions of blue sharks, albacore and skipjack tuna, pomfrets, and pelagic armorheads, as well as numerous fur seals, seabirds, sea turtles, salmon, and other fishes (Yatsu et al., 1994b). Similar numbers could be expected for the vessels of the Republic of Korea and Taiwan, which comprised a third of the vessels setting driftnets for squid in the North Pacific (Fitzgerald et al., 1994). Reports of this bycatch led to a public outcry to ban the use of pelagic driftnets, known as "walls of death."

The increasing efficiency of harvesting methods, together with increasing numbers of harvesters, often has resulted in precipitous decreases in abundance within populations of target species (Rosenberg et al., 1993). In addition to the obvious economic problems, this can cause profound changes in the ecosystem. For example, in the fishery for bottom fish on Georges Bank (in the Atlantic Ocean east of Massachusetts), 67% of the fish caught in 1963 were the prized gadoids (cod and hakes) and flounders, whereas 24% was made up of unwanted dogfish sharks and skates. By 1986 the dominant catch had shifted dramatically, with 14% gadoids and 74% sharks and skates (Sissenwine & Cohen, 1991). Such changes in populations of large predators could cause profound effects throughout the food web. Similar situations occur in both bottom and pelagic fisheries around the world.

The shift in species fished on Georges Banks is one response to the decreased abundance of some target species. Similarly, fishermen are searching deeper waters for additional species to exploit (Vecchione, 1987), resulting in bycatch and other impacts in new areas. Another response has been development of methods to enhance population size by hatching and releasing the young (Omori et al., 1992). Taking this a difficult step further, some species are reared to harvestable sizes by either exsitu aquaculture or in-situ cage or raft culture (Tseng, 1992). Along with problems involving nutrient loading, these culture methods have caused concerns about reduction in genetic variability in the cultured species (Upton, 1992). When exotic species are cultured, the introduction of these alien species (either accidentally or deliberately) into ecosystems (Carlton, 1989) has caused substantial problems with serious ecological and economic results, including reduction in the number of native species (Carlton, 1992).

Fisheries Agencies

A major role of marine fisheries agencies has been to determine why catches of commercial species fluctuate widely. The overall goal has shifted from maximizing catch to achieving sustainable use of the renewable resources (Rosenberg et al., 1993). Many early efforts focused on field surveys of abundance or spawning biomass for data input in single-species population models. The resulting estimates of resource availability have been used with greatly varying success by fisheries managers to determine the amount of catch that can be allowed while maintaining commercially viable populations.

The focus of fisheries management has progressed from single species to multiple target species (e.g., Murawski, 1993) to ecosystems (such as the large marine ecosystem approach of Sherman et al., 1990). For an ecosystem management effort to have any chance of success, information is needed on all abundant or ecologically important species. One aspect that has received particular attention is variability in the recruitment of young stages of commercial species to the fisheries and the interactions of ecosystem dynamics with recruitment (Fogarty et al., 1991; Frank & Leggett, 1994).

Over the years, fisheries agencies have increasingly had to deal with other marine resource issues. In addition to traditional foodfishes, other natural resource products (e.g., aquarium fishes, collectable seashells and coral, etc.) are harvested from the sea, including some with biomedical importance (Wright & McCarthy, 1994). Also, the long history of managing marine populations made fisheries agencies the organizations of choice for protecting threatened and endangered species (Upton, 1992), as well as insulating the species from fishing activities. In some countries, the agencies participate in the design and management of marine parks and other natural reserves. Along with the parks and the endangered species responsibilities, fisheries agencies become involved in regulating non-consumptive uses of living marine resources, such as whale watching off New England. Efforts to preserve ecosystem integrity and to protect coastal nursery areas have moved the agencies into the broad field of environmental protection and pollution abatement. This in turn has forced the inclusion of pollution indicator species (Parker, 1991) into fisheries concerns.

Often during difficult economic times, people try to supplement or replace lost income by harvesting natural resources (e.g., Vecchione, 1987). Also, changes in strategies for managing fisheries resources can cause widespread direct and indirect effects on the economics of coastal communities (Smith, 1995). One of the most difficult aspects of implementing new regulations is the resistance to changes in traditional fishing methods. Thus, human cultural implications have had to be considered in addition to attempting to manage the harvest (e.g., Smith, 1994).

These complex tasks have required the development of an extensive data-collection infrastructure in addition to ongoing resource surveys. Many databases exist that contain vast detailed information about changes in abundance of many fish, crustacean, and cephalopod populations and their genetic variability. Furthermore, many specimens have been deposited in archival museums (Collette & Vecchione, 1995). This combination of data and specimens is particularly important because historical data can be found for comparisons with present or future conditions (Allmon, 1994; Tyler, 1994).

Collette and Vecchione (1995) recently summarized the importance of systematics and taxonomy in fisheries. Many workshops and study panels have pointed to an upcoming crisis in the systematics of marine invertebrates (Winston, 1992). There is a lack of replacements for current research positions at the Smithsonian Institution and other major museums around the world for many groups of marine invertebrates (Feldmann & Manning, 1992). Over a two-decade period (1976–1995), the number of fish specimens in collections in the United States and Canada increased by 77%, while over the same period the number of curators/researchers responsible for those collections decreased by 73% (Poss & Collette, 1995). A major reason for this worldwide decline has been a continuing decrease in funding, prestige, and number of positions in systematics (Cotterill, 1995). There is a need to train additional systematists for placement in an increased number of positions, both in fisheries agencies and in the scientific community at large, so that experts are retained for every important group of organisms. In addition to training additional systematists, the systematics community must find better ways to disseminate knowledge of their groups and train fishery biologists, ecologists, and others to use up-to-date taxonomy as a tool in their research. Resource management agencies should hire systematists to provide the agencies with needed expertise and to bear a share of the costs of funding systematics.

Fisheries agencies that already are surveying for other fisheries-related problems could easily and with little added effort or expense expand those surveys to focus on questions of biodiversity. Coordinating these activities with museums and academia would allow maximum return while minimizing duplication of effort (Hoagland, 1994).

Proposed Actions

Some proposals made to the U.S. National Oceanic and Atmospheric Administration (NOAA) are listed below as an example of how a federal agency can expand its efforts in marine biodiversity. We feel that these proposals could be applied to fisheries agencies worldwide with only minor adjustments (Fig. 1).

1. DEVELOP INFORMATION SYSTEMS FOR BIODIVERSITY METADATA

Fisheries agencies have databases on the distribution of most economically important organisms and some other species that live within their respective geographic area, in addition to concurrent environmental parameters. Museums are computerizing information on the specimens in their collections. Furthermore, visual information (e.g., videotapes recorded by submersibles) has been archived and could be used to document biodiversity that was observed in areas difficult to sample conventionally (Felley & Vecchione, 1995). All of the data mentioned above can be accessed by metadata to form a marine biodiversity database that can address questions such as whether there have been changes in marine biodiversity similar to those reported in terrestrial and freshwater ecosystems.

Biodiversity metadatabases can be constructed from minimal data: species name, locality, depth, date, and either catalog or station number to refer back to the original complete records. Accuracy of species identification and linkage to voucher specimens deposited in archival museums are vital to insuring taxonomic credibility of the databases. Such databases can provide a current and retrospective picture of biodiversity to detect any changes that are occurring. Biodiversity databases will reduce duplication of collecting efforts in carrying out marine biological inventories. Properly constructed, these databases can be integrated with other national efforts to catalog biological diversity, including all biomes (e.g., the U.S. National Biological Survey and the proposed National Biodiversity Information Center). Such efforts are already well under way in Australia, Mexico, and Costa Rica.

2. EXPAND EXISTING SAMPLING AND MONITORING PROGRAMS

Most fisheries agencies conduct field surveys to provide information for resource management. The major cost of marine sampling is putting a research vessel to sea. The cost of preserving a broad taxonomic suite of material for the study of diversity is comparatively much less. A team of taxonomic specialists and field technicians should be added to fisheries laboratories currently carrying out resource surveys. These personnel could be employed directly by the agencies or under contract from universities, etc. They would be charged with sampling a broad array of organisms, not just those of economic importance. They would utilize additional types of gear and, if necessary, special techniques to preserve specimens. They would facilitate the flow of well-preserved voucher specimens to systematic specialists at universities and museums, and study part of the material themselves.

3. DEFINE DETAILED QUESTIONS AND DEVELOP METHODS TO ASSESS AND MANAGE BIODIVERSITY

Detailed achievable goals have not yet been defined for assessing and managing marine biodiversity. One such question currently being posed is whether an all-taxon survey of a marine area is feasible. A demonstration project, limited in time and area, should be established to identify specific research and management goals and capabilities for long-term information and conservation needs. This project would involve specific sites of contrasting characteristics to define attainable goals, which then could be expanded as necessary throughout the nation's waters.

4. INVENTORY SANCTUARIES AND RESERVES

Sanctuaries and reserves often have been established based on politics rather than biology. Boundaries have been drawn based on governmental jurisdiction instead of knowledge about the life histories of resident organisms. Existing biodiversity in these areas cannot be maintained without

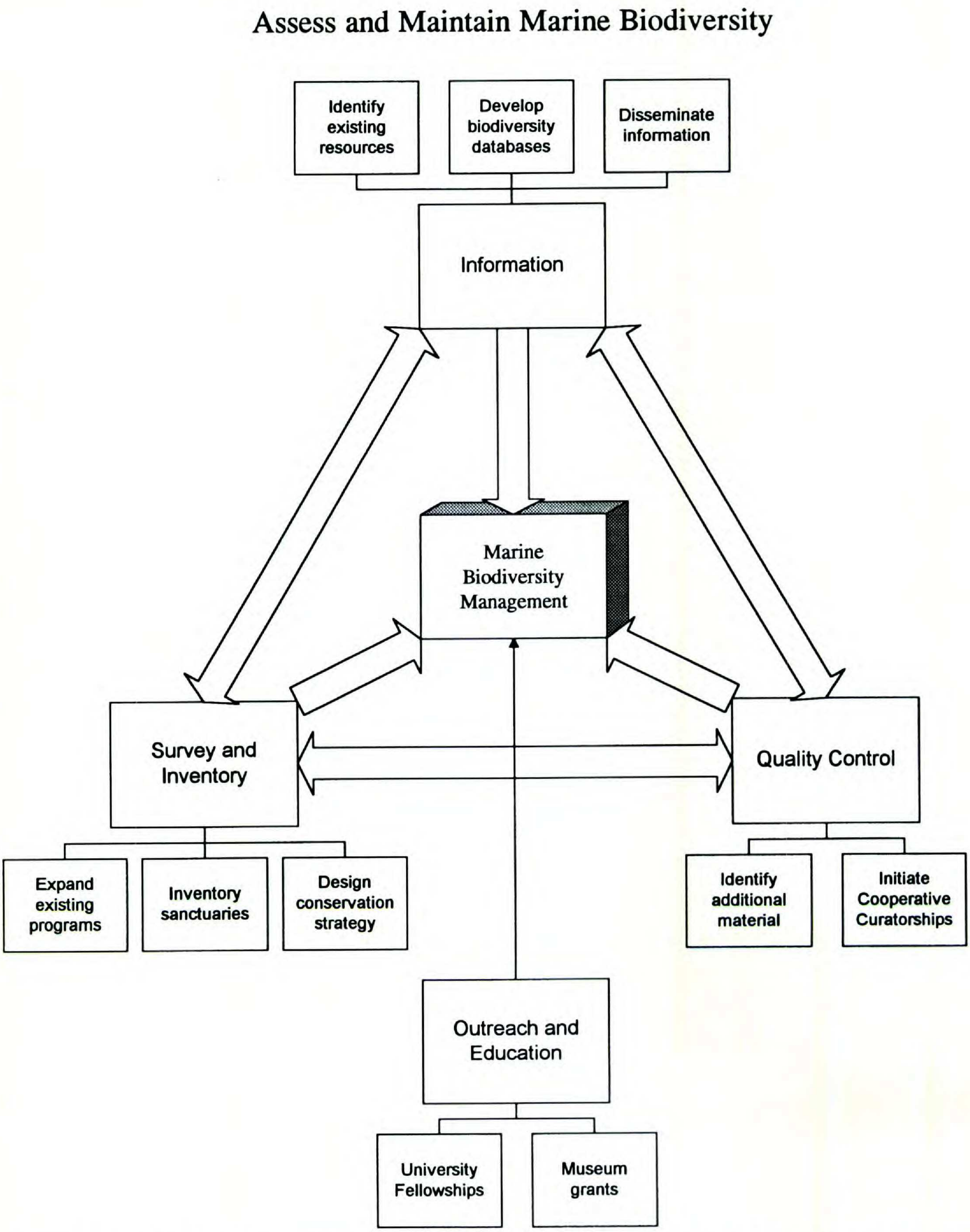

Figure 1. The 10 actions proposed for fisheries agencies in the text, and how they fit into a plan to assess and maintain marine biological diversity.

knowing what species live in each. In order to manage these areas, their species composition and abundance must be inventoried. This task has two components. First, any existing information on the biota of each sanctuary and reserve should be synthesized. Second, these syntheses should be supplemented by additional collecting from ships and in-situ observations. Voucher specimens documenting the occurrence of different kinds of organisms in the sanctuaries should be deposited at nearby museums. After this, life-history information is needed to determine whether populations are self-sustaining within the boundaries of the sanctuary or if modification of the boundaries is necessary to maintain populations of key species.

5. STUDY ADDITIONAL MATERIAL COLLECTED OR ARRANGE FOR ITS STUDY

Much new material will be collected by the fieldwork described above and will need to be identified. This will require an increased number of specialists in the taxonomy of groups of marine organisms that now lack adequate systematic experts. Specialists need to be added to museums to study poorly known speciose groups of marine invertebrates, such as small bivalves and gastropods, sponges, cnidarians, cumaceans, organisms parasitic on fishes, various groups of worms, and microorganisms. Such specialists are vital to assure the accuracy of identifications. Furthermore, a relatively small number of specialists will then be available to train other biologists in taxonomy as needed. In order for systematics to attract students, more positions and funding must be made available.

6. DEVELOP A PROGRAM OF COOPERATIVE SYSTEMATICS CURATORSHIPS

Insure that at least one expert exists for every major group of organisms by setting up a system of cooperative curatorships in museums holding major collections of marine specimens. These systematists would be hired or contracted by fisheries agencies with consultation of the museums in which they are located, similar to the National Systematics Laboratory at the U.S. National Museum of Natural History. Agencies should insure that there are positions available for the systematists they train to identify organisms, write keys, study phylogeny, and produce monographs. Taxonomic credibility must be maintained for the biodiversity program to be effective.

7. HELP FUND MUSEUMS HOLDING LARGE COLLECTIONS OF MARINE SPECIMENS

Good collections must be maintained to avoid expensive repeat sampling. Information from a large number of such collections is needed to create marine biodiversity databases. Cooperation with museums is vital to the success of a marine biodiversity program because museums hold most of the collections of marine organisms that serve as vouchers for species occurrence and employ most of the limited expertise available to identify many groups of marine organisms. Most museums are currently understaffed at all levels, so the necessary information will not become available for a long time unless these institutions receive assistance. Such funds could also be used to facilitate the incorporation of important collections maintained by individual investigators at universities, marine stations, and fisheries laboratories, into archival museums so that the information can become part of the museum databases.

8. DEVELOP FELLOWSHIPS IN SYSTEMATICS

Training additional marine systematists can be accomplished by developing a fellowship program to support students in cooperating graduate schools, similar to the U.S. Fish and Wildlife Service's Cooperative Research Program and NOAA's Cooperative Marine Education and Research programs (CMER) at several northeastern U.S. universities. Some universities will be associated with museums housing Cooperative Systematics Curatorships. These fellowships could provide additional training to current fisheries employees to fill some of the new positions described above.

9. DESIGN NEW WAYS TO DISSEMINATE TAXONOMIC INFORMATION

New ways are needed to transfer information on taxonomy to a wide array of user groups and to simplify learning of a taxonomic discipline. Novel tools include multimedia computer keys to facilitate identification of marine biota by fishery biologists on shipboard, and fisheries agents collecting statistical information at landing ports. Computerized information could be distributed via the Internet or on CD-ROM. These systems could best be designed in cooperation with ongoing project development such as that at the Smithsonian Institution and the Institute of Taxonomic Zoology at the University of Amsterdam.

10. PUBLISH MARINE BIODIVERSITY RESEARCH

An outlet is needed for monographs related to marine biodiversity such as taxonomic revisions and the series of larval fish guides being produced by fisheries laboratories (e.g., Matarese et al., 1989). Credible lists of species identifications and abundances in local ecosystems should be published either electronically or in journal format. Along with this, a marine biodiversity newsletter could be produced electronically for rapid dissemination of informal information.

What Are the Benefits?

A successful marine biodiversity program will produce information that will assist in managing living marine resources and assuring that representative segments of the biota that inhabit the ocean today will be here for our children to appreciate. Fisheries agencies should take the lead in marine biodiversity research and conservation. An additional benefit of a formal biodiversity program would be to demonstrate a pro-active position for fisheries agencies in understanding marine ecosystems for their future protection.

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